Physics Parameterization for Seasonal Prediction

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LONG-TERM GOALS

This 6.1 project is part of a long-term effort to identify and solve the major challenges of parameterizing the impacts of physical processes on atmospheric predictions extending out to seasonal time scales. Achievement of this goal will represent a significant step towards the development of an operational global earth system model targeted by the national Earth System Prediction Capability-Research, development, and Operations (ESPC-RDO) effort, in which the United States Navy is a participant.

OBJECTIVES

This project targets development of a "unified" treatment of atmospheric mixing within the Navy Global Environmental Model (NAVGEM) suitable for extended range prediction that includes not only boundary layer mixing, but mixing by shallow to mid-level convective clouds, as well as deep convection. The project will pursue a more consistent and realistic treatment of the relative magnitudes of these various mixing processes, focusing on the hydrologic cycle, but also addressing related momentum drag balance issues.

APPROACH

We are currently focusing on ensuring a more comprehensive inclusion of key processes in our representation of the hydrologic cycle in NAVGEM. Some critical steps have been taken during the past year with the implementation of a prognostic cloud scheme and separate treatments of deep and shallow convection. We continue to work towards improved fidelity of our physics codes to current understanding of atmospheric processes, and are seeking to adapt and test new physics treatments as well, particularly those developed under this DRI. Noting the tremendous importance of the Madden Julian Oscillation (MJO) for predictability on extended timescales, we are participating in the MJO Diabatic Heating Model Inter-comparison Project, a joint effort between the Year of Tropical Convection (YOTC) Program and the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS). This large collaborative effort is investigating the sensitivity of the representation of the MJO to various model formulations, providing us an excellent opportunity to leverage our development efforts under this DRI project. The NAVGEM multi-year simulations and

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20-day hindcasts provided for this collaborative investigation will serve as a baseline against which we will evaluate performance enhancements gained through our parameterization development. Extensive observed and analyzed data available through the YOTC Program will be used to help evaluate model performance in this study. Evaluation efforts will be augmented through analysis of errors on shorter timescales using the state-of-the art data assimilation component of NAVGEM.

The key performers on this project are Drs. James Ridout (PI) , Maria Flatau, and Shouping Wang, all employed by NRL in the Marine Meteorology Division, and Dr. Jan-Huey Chen, a UCAR visiting scientist at NRL.

WORK COMPLETED

We have made some significant progress this year in our parameterization development for NAVGEM under this project. The synergy between this project and an NRL in-house effort resulted in the development of a two-phase cloud scheme that is currently undergoing testing for utilization in the NAVGEM operational release candidate. The scheme represents an extension of the GFS single-cloud parameterization to include, in addition to an explicit treatment of both liquid and ice condensate (thus providing for conservation of latent heat energy), an improved treatment of convective cloud water and an improved representation of the correspondence between diagnosed cloudiness and grid-scale condensation. Extended range hindcasts and comparisons of simulated cloud liquid water with satellite retrieved fields from the TRMM Microwave Imager were a key factor in the development of the new scheme by the PI of this project.

In a separate development, a modification was made through this work to the Slingo cumulus cloud fraction scheme used in NOGAPS for over 20 years. The change is a scaling of the cloud fractions by the convective cloud base mass flux to ensure that the cumulus cloud fraction vanishes in the limit as mixing by the convective scheme approaches zero. Though simple, the impact is considerable. The clearest positive impacts in comparisons with satellite retrieved cloud cover from the International Satellite Cloud Climatology Project (ISSCP) were seen in extended integrations of NAVGEM using the Emanuel convection scheme (Emanuel 1991; Emanuel and Zivkovic-Rothman 1999; Peng et al 2004). With our planned transition to the combined Simplified Arakawa-Schubert / GFS shallow convection scheme package (Han and Pan 2011) for the operational weather forecast release of NAVGEM, the effect of this change in limiting a severe overprediction of shallow cumulus cloud cover in this context was also very significant.

We completed a 20-year integration of a NAVGEM prototype (without the prognostic cloud water), as well as a series of 50 20-day hindcasts of MJO episodes from 2009/2010 that occurred during the YOTC observational period. We have submitted the considerable volume of diagnostic data from the runs for the model intercomparison effort of the YOTC/GEWEX project referred to in the “Approach” section above.

We have completed a NAVGEM integration for 2004 – 2010, generating diagnostic output for the CFMIP (Cloud Feedback Model Intercomparison Project) Observation Simulator Package (COSP) (e.g., Bodas-Salcedo et al. 2011). Data have been provided for COSP analysis to Dr. Zhuo Wang at the U. Illinois.
A polar mode EOF study of reanalysis data was completed as part of a an effort to investigate connections between the MJO and polar circulations. This analysis was then applied to our 20-year NAVGEM integration.

RESULTS

The two-phase prognostic cloud water treatment developed for NAVGEM enables the model to conserve latent heat energy. Although sometimes referred to as a "two-species" scheme, "two-phase" more accurately reflects the recognized bulk nature of the parameterization, where each phase, for example, is assumed to include a precipitating and non-precipitating component. There remain, as with other parameterizations, inconsistencies and unknown/stochastic features that will need to be addressed as we work towards a more "unified" representation of the water cycle in the model. One such area is the correspondence between diagnosed cloud cover and prognostic cloud condensate. Although an effort was made to condition key cloud processes on diagnosed cloud cover, problems posed in accounting for cloud-scale processes from the macrophysical perspective afforded by current model spatial resolutions will need to be investigated. A key advance associated with the two-phase code is that it provides for a representation of convective cloud condensate by making evaporation of water condensate under dry conditions dependent on the amount of parameterized convection. Without this treatment, much of the convective cloud liquid water evaporates much too rapidly, negatively impacting radiative interactions.

The modified cloud cover treatment provides an improved representation of the convective cloud cover variable, *cufrac*; in particular, its dependence on the grid-scale convective cloud base mass flux, *cbmf*:

$$cufrac = \left(\frac{c1 + c2\log(rain + c3)}{c1 + c2\log(c3)} \right) x \left(\frac{cbmf}{(\rho w)_{cb}} \right)$$

The factor on the far right represents an estimate of the grid-scale coverage of updrafts at cloud base level. The quantity $(\rho w)_{cb}$, the mean local mass flux at cloud base level, is currently taken as a constant, but further parameterization is possible. The first factor, the log-rain scaling, where *rain* is the convective rainfall, is the original Slingo (1987) formulation normalized by its value for zero rainfall. The log-rain scaling helps to account for enhancements in cloud cover associated with larger amounts of convective rainfall (resulting, for example, from less evaporation of cloud water and more entrained mass flux above cloud base under moist conditions.) An example of the impact of the modification for deep convective cloud cover is shown in Figure 1.

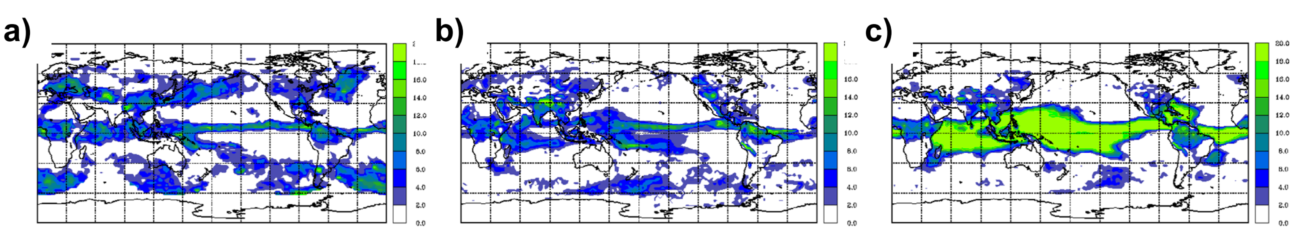

Figure 1: Mean fraction of deep convective clouds (tops higher than ~450 hPa) for May 1991: a) ISCCP (Rossow and Schiffer 1991) D2 retrieval (from daytime data), b) NAVGEM with Emanuel convection and modified cumulus cloud fractions, c) NAVGEM with Emanuel convection and unmodified cloud fractions.

In conjunction with the Simplified Arakawa-Schubert / GFS shallow convection combination, the scheme has little impact on deep convective cloud cover, but acts to preclude parameterization of excessive amounts of shallow cumulus cloud cover.

Our completed 20-year NAVGEM prototype integration has only weak intraseasonal variability. A follow-up run is planned with an updated version of NAVGEM with the two-phase cloud scheme and increased entrainment in the parameterized convection. The current run is being analyzed both by the leaders of the intercomparison project as well as by ourselves. An interesting feature of the run is its representation of the polar circulations. The first EOF of the 700 hPa height field is plotted in Figure 2 below left from NCEP reanalysis data, and right from the NAVGEM 20-year run.

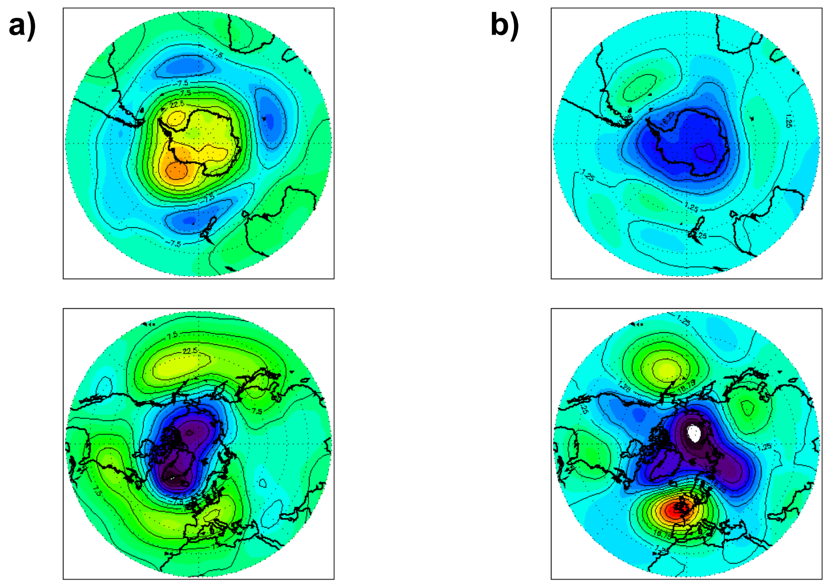

Figure 2: The first EOF of the 700 mb height for boreal winter (DJF) calculated for the entire globe from a) NCEP reanalysis data b) NAVGEM 20 year run.

The figure shows that in the reanalysis the southern and northern polar annular modes are out of phase; this relationship is not present in the NAVGEM data. One hypothesis is that the out of phase relationship may be due to the impact of the MJO on polar circulations. As we improve our representation of the MJO in NAVGEM, we plan to revisit this issue to see if the nature of the phase relationship between the southern and northern polar modes changes in the simulations.

IMPACT/APPLICATIONS

The parameterization development under this project is expected to contribute to future strategic planning capabilities of the United States Navy. In addition to helping enable skillful extended range prediction, benefits to current short- to medium range forecasting capabilities are also expected.

TRANSITIONS

The two-phase prognostic cloud scheme and the modified cloud fraction treatment have both been transitioned to 6.4 for possible transition to operations.

RELATED PROJECTS

NOGAPS/NAVGEM Platform Support (PI Dr. T. Whitcomb). This related project is expected to benefit the 6.1 project discussed here by facilitating coordination of efforts with collaborators on other projects funded through this DRI.

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PUBLICATIONS

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